Department of Athletic Performance
National Taiwan Normal University
A thesis submitted for the Master of Science Degree

Kicking moving object: is target speed used in guiding Taekwondo back kick?

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Taipei, Taiwan

June, 2017

摘要

論文題目：踢擊移動物體：目標速度是否會影響跆拳道後踢表現？

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跆拳道是一種技擊型運動，其以踢擊作為主要得分方式。後踢為跆拳道重要的踢擊技術之一，由於後踢動作是以直線朝對手的身體或是頭部踢擊，因此常被作為旋踢攻擊的反擊動作。在跆拳道比賽中，雙方選手會為了攻防而不停的移動位置，有效的踢擊必須於準確的時間擊中移動目標，方能於比賽中獲取分數；然而，目標物的移動速度是否會對踢擊動作時間和空間準確度產生影響？**目的：**本研究針對不同速度目標物對跆拳道後踢的動作時間、動作起始時間和空間準確度進行探討。**方法：**本研究招募十名優秀男性跆拳道選手參與實驗，實驗參與者須對目標物進行後踢, 每位實驗參與者皆須對四種不同速度之目標物進行十次踢擊，每次踢擊將會以每秒 300 幅之高速攝影機錄影，再使用 Kinovea 軟體擷取運動學資料，以計算動作時間、時間誤差、目標空間準確度和角度空間準確度的數據。統計分析將使用單因子重複量數變異數分析對不同速度之目標物的動作時間和時間誤差進行檢測，而不同速度之目標物的目標空間準確度和角度空間準確度, 則用皮爾森卡方進行獨立性檢驗，統計顯著值設為α = .05。**結果：**動作時間和時間誤差在不同的目標速度下沒有顯著差異, 但目標空間準確度和角度空間準確度則與不同目標速度有關連性，當目標的速度增加，目標空間準確度和角度空間準確度會隨之下降。**結論：**目標的速度並不會影響跆拳道後踢動作時間和動作起始時間，但卻與空間準確度有關聯性。

關鍵字：跆拳道、後踢、動作時間、動作起始時間、空間準確度

Abstract

Taekwondo is a full contact sport where most points are scored through kicks. Back kicks are used for counter kicks of round house kick. To score points, the kick has to be accurate both spatially and temporally. However, during the Taekwondo fight, both athletes are constantly moving, making it a moving target to attack. How does the moving speed of the target affect the characteristics of the kicking movement? The purpose of the study was to investigate the effect of different speed of moving target on the movement time, movement initiation, and spatial accuracy of Taekwondo back kick. Ten elite Taekwondo male athletes were recruited for the experiment. The participants were asked to kick a stationary object (0 speed) and a moving object with 3 different speeds in a random order with 10 trials each. High-speed cameras with 300 fps and the Kinovia digitizing software was used for this experiment. The movement time (MT), temporal error (TE), target spatial accuracy (TSA) and spatial accuracy of the sand bag angle (ASA) of the back kicks were examined. The one-way repeated measure ANOVA was used for the speed conditions on MT and TE. Chi Square tests of independence were used for the 4-speed conditions in SA and 3-speed conditions in ASA. The α level of significance was set at .05. The results showed that there was no significant effect of object speed in MT and TE. The Chi square results showed the significant associations between the different speed conditions in TSA and ASA. In conclusion, the speed of object did not influence the movement time and the movement initiation of the back kick. The spatial accuracy, however, had strong association with the target speed.

Keyword: Taekwondo, Back Kick, Movement Time, Movement Initiation, Spatial Accuracy

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CHAPTER I INTRODUCTION

Background of the study

Taekwondo is a full contact sport where most points are gained through kicks (Kazemi et al., 2006). Taekwondo athletes use numerous types of kicks in matches and these different kicking techniques have different scoring efficiencies (Tan & Krasilshchikov, 2015). In the past, the kick used the most in the competition was round house kick (Lee, 1983 and Lee, 1998; Nien et al., 2004; Koh & Watkinson, 2002). Back kicks are used for counter kicks of round house kick due to the direct contact straight to the opening of round house kick toward the trunk or to the head of the opponent (Roh & Watkinson, 2002; Lee, Chin & Liu, 2005). With the right timing, the back kick can destroy competitors offensive attack rhythm (Eddie, 1989; Lee, 1996). However, one should take into account that the target will move during your own movement, this means one should guide the feet to a future location of the moving target and to arrive there in time for a full impact force.

Speed and accuracy is very important in Taekwondo scoring, because athletes need to move in a sufficient time in order to reach the target area of the opponent before the opponent avoids the attack. Taekwondo uses electronic protectors for headgears and body protector, therefore for points to be obtained one needs to be accurate enough to have their foot arrived on the target area. In Fitts' (1954) tasks, participants move their hands from one location to the target repetitively as quickly and as accurately as possible. There are two targets with the same width, W, and A is the distance apart (center to center distance). The relationship between the movement time (MT), the movement amplitude (A) and the required accuracy (target width, W) has become well known as the Fitts' law. Most research in speed and accuracy is based on the arm, because the arm is for a more defined motor task such as grasping and writing (Tillaar & Ulvik, 2014). Although several studied reported that the lower limber conforms to the Fitts' law, it was not definite whether the different kicking movement would reveal the same effect. Taekwondo back kick is not only a very good example of fast discrete lower limb movement, but it can also be explored between the relationship of speed and accuracy. Speed and accuracy are two dominant factors in kicking; In order for speed and accuracy to take place in back kick, certain aspects needs to be taken into consideration, such as the direction in which we move our foot and continuously adjusted on the basis of the target perceived position for the best optimal speed and accuracy.

In Taekwondo competition, opponent is always continuously moving back and forth; therefore, intercepting moving target is required in order for the kicks to be scored. In recent study we see that the acceleration of the hand is also under such unceasing control (Brouwer et al. 2002). The change in speed of target can have an influence in participant's judgment of where the target will land, this way the reaction time will also be affected and how the participants respond before their optical information has been completely interpreted enabling one to modify the movement as the interpretation continues (Van, 1992).

Studies have shown that the optimal time for interception of moving object is the changes in speed of target object, which can have the same effect on required temporal precision. However, there will be changes in response and these are the target speed in which it produces a larger change in response speed. The temporal aspects of the task would be target size to the increase in speed thus roughly specifies time to contact between the upcoming objects to the possible kicker (Lee et al., 1983; Savlsbergh et al., 1991). Furthermore, studies have shown that participants will have anticipation and will begin their action (Tresilian, 1999). Therefore, temporal precision will show restrictions with the movement amplitude on the performance of the interceptive targeting task (Tresilian, & Lonergan, 2002). For interception of the moving object to occur, the intercepting effector and the moving object must arrive at the same spatial location at the same moment in time. There are constrains for the movement of the intercepting effector both spatially and temporally.

Purpose of the Study

The purpose of the study was to investigate the effect of different speed of moving target on the movement time, temporal error, and spatial accuracy of the Taekwondo back kick.

Research questions

The research questions were as follows:

1. Will the movement time decrease when the speed of target increases?
2. Will the movement initiation be influenced when the speed of target increase
3. Will the spatial accuracy decrease when the speed of target increases?

Hypothesis

1. Movement time will decrease when the speed of the target increases.
2. Movement initiation will be influenced when the speed of target increases
3. When speed increases, the spatial accuracy will decrease.

Operational definition

1. Back Kick: turning one's body backward executing a kick and striking opponent with the heel, deliver a straight kick in a fixed position to the target (Kang, 2011)
2. Kicking Distance: The distance between the front foot of the participant and the projection of the target onto the floor. The leg length of the participant, which is measured from the heel to the hip, is used as the kicking distance.

3. Target area: The height of the target on the sand bag is based on each participant abdomen (belly) .A total of 4 concentric circle is drawn on the center of the sand bag with increasing diameters of 10 cm, 20 cm, 30cm, and 40 cm.
4. Movement time (MT): The time between the movement initiation and the arrival of the foot on the target area (Brouwer et al., 2002)
5. Temporal Error (TE): The time between the movement initiation of the participant and the moment where the target is perpendicular to the ground. Negative TE indicates the movement is initiated before the target arrives at the perpendicular position.
6. Spatial accuracy: There were 2 measures of spatial accuracy. The first one, target spatial accuracy (TSA), was based on the moment the kicking foot arrives on the target area and recorded with a high speed camera to measure the points scored in each back kick. The inner circle with the most point is 4 point and the circle followed by the inner circle is 3 point on the second circle, 2 point on the third circle and lastly 1 point on the outer circle. If the foot lands outside of all circles it will be regarded as 0 point. The points are identified according to the white strap attached to the inner and outer arch of the foot. The second spatial accuracy measure, spatial accuracy of the angle of the sand bag (ASA) at the foot-sand bag contact, was determined by subjective rating. Level 4 is registered when the sand bag is at the perpendicular position for foot contact, followed by 3, 2 and 1, when sand bag is further away from the perpendicular position at foot contact.
7. Stationary: Object halts perpendicular to the ground. (Speed 1).
8. Speed Level (SP#): The sand bag is released from three different angles creating 3 levels of speed: 13.95 m/s for SP2, 27.9m/s for SP3, and 41.84 m/s for SP4.

CHAPTER II LITERATURE REVIEW

Back kick

Taekwondo Back kick is the most powerful kick in both men and women (Pieter & Pieter, 1995); moreover, it can be used as an offensive or defensive technique (Lau, 2013). A back kick is also called a spinning back kick, horse kick, donkey kick, mule kick or the traditional Korean language the "Dwi-Chagi". This action is performed by kicking backward onto the opponent behind you, like a horse, with the striking surface of the bottom of the foot, normally the heel part. Figure 1 shows four phases in a back kick. The rotation phase consists of facing the target first, and then the body pivots away from the target. During the contact phase, the kicking leg must be tight and close to the supporting leg, and strikes with the heel or the foot blade. The restoration phase is the pull back of the kick and back to kicking position. The turning motion provides a lot of power to the back kick, one should look over the shoulder when delivering the back kick to know where the target area is situated in and to maintain a firm balance. The balance can be broken off when kicking without proper procedure. The best kicking height of back kick is the kickers' sternum (Estavan & Falco, 2013).

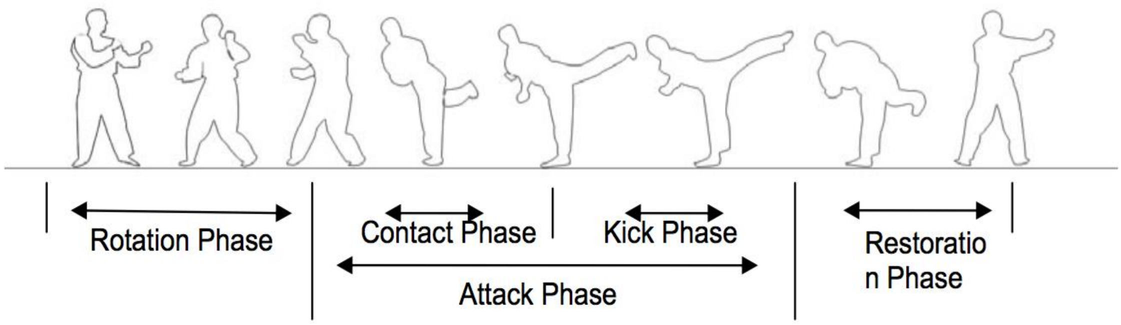

Figure 1. Step by step back kick model (Lee & Chen, 2008)

Back kick not only can be used as an offensive kick, but it is more often used as a counter attack kick, destroying the offensive rhythm of the opponent and can break opponents' balance

(Eddie, 1989; Lee, 1996). Back kick requires right timing for speed and accuracy to take place in order for a valid point to be scored. Therefore, Taekwondo athletes needs best timing and enable them to guide their feet to future location of the target. Taekwondo uses various techniques, and these techniques have different effect and speed. It has been shown that the right and left legs of men and women had no significant difference in their kicking speed (Pieter & Pieter, 1995).

Speed and Accuracy

The relation between movement speed and accuracy is one of the most robust phenomena in human movement performance. Common sense teaches us that when we perform movements faster, we make more mistakes or errors in terms of the goal we want to achieve. These situations support the adage "haste makes waste"; a long standing perspective about motor skills. Fitts (1954) proposed a mathematical model that was a critical step to describing formally, the speed-accuracy phenomenon and it has become one of the most significant laws in motor control. Fitts and Peterson (1964) asked participants moved their hands from a start location to the target as quickly and accurately as possible. He used two independent variables (A = amplitude; W = target width) to calculate the index of difficulty, $ID=Log_2(2A/W)$. The index of difficulty is the most important factor in Fitts's law to determine the average movement time. Fitts described this relationship between movement time, amplitude and target width as $MT = a + b \log_2 (2A/W)$. The higher the value of ID, the longer the movement time, therefore, slower the speed of movement. Thus, Fitts' law explains the speed-accuracy trade-off by implying an inverse relationship between the movement difficulty and the movement speed.

Fitts explained the relation between movement speed and accuracy in relation to the limited information processing capacity of the human system (Fitts 1954). When the number of stimulus response alternatives increases, the system needs more time to process this information and resolve the uncertainty about alternatives (Fitts, 1954; Fitts & Peterson, 1964; Schmidt & Lee, 2005). Fitts's law can be applied to a variety of contexts of movements, including everyday activities. This law has also been conducted under different situations, such as using feet, arms, hands, movements conducted underwater, and different populations (young and old) (Goggin & Meeuwsen, 1992; Langolf, Chaffin, & Foulke, 1976; Newell & Wade, 1978; Welford, 1969). Fitts' law describes the speed-accuracy trade-off of limb movement toward a stationary target. Fitts' Law does not apply to the situation where the aimed target is moving which is often occurred in many sport events.

Taekwondo kicks emphasize kicking accuracy as well as kicking speed. In Taekwondo, one needs to have the right speed to kick moving object. When the speed of the kick is too slow, the opponent might dodge the kick. Taekwondo athletes use electronic body protectors and headgears for scoring. Without accuracy in kicks, the foot will not land in the right target area on the sensors of the electronic protectors, therefore the points will not be scored. Kicking a stationary target is considered an easy task, but in Taekwondo competition, the opponent will move back and forth making it difficult to score points. Nevertheless, Taekwondo is a sport where your target is moving constantly. Temporal accuracy also needs to be taken into consideration.

Temporal accuracy

Taekwondo Athlete's need to move as quickly and accurately as possible, and temporal accuracy is also a factor that needs to be taken into account for kicking moving object. By temporal accuracy, we refer to as the difference between the actual movement time and the criterion time of the task (Schmidt, 1969). Literature has shown that increasing movement velocity within the same criterion movement time results in a decreased timing error (Newell, Hoshizaki, Carlton, & Halbert, 1979; Schmidt, 1969). Many studies of the movement timing tasks suffered the limitation that the independent variables, such as manipulations of duration and velocity, were confounded (e. g., Ellis 1969). In this case, movement time and movement velocity have rarely been manipulated independently. It is commonly the condition that short movement time has high velocity and long movement time has low velocity. The findings from early studies suggested that timing accuracy was affected by movement velocity but little was learned of time effect of timing accuracy.

Newell et al. (1979) examined systematically the movement speed and timing accuracy function over a range of movement velocity from 4 to 150cm/s. Their results suggested that the mean percentage of the movement time AE (absolute error) had little or no difference between different times at the same average velocity. In addition, timing accuracy decreased with longer movement times and slower average velocities. The velocities effect was independent of movement time, and suggested that average velocity is a main factor to determine the temporal accuracy in discrete timing movements. However, to interact with the environment (e.g., catch frisbee or bat hitting) one needs to have a specific movement toward a certain position at a certain time. Thus, the movements toward the incoming object have to be specified according to the temporal accuracy and spatial accuracy (Rieger, 2007). In Taekwondo competition, the opponent is always continuously moving back and forth. In this case, both focus on the spatial and temporal accuracy might give us a different prospective in movement accuracy.

Interception of moving target

Intercepting a moving object requires that the interceptive effector (hand or bat) get to the right place at the right time (Tresilian, Plooy, & Carroll, 2004). A large number of findings specified that the interception of moving object highlights the temporal aspect of the task, which uses the ratio of image size to its expansion rate that is approximately specifies time to contact between the upcoming object to the possible batter or catcher (Lee et al., 1983;

Savlsbergh et al., 1991). In addition, studies found that the participants anticipate the start of their activity when moving object reached a specific moment or criterion value (Michael et al., 2001). Although moving quickly increases the temporal accuracy, it decreases the spatial accuracy, so again a compromise must be found (Brouwer et al., 2000).

Most studies of interceptive tasks showed that the participants have a tendency to move their hand more quickly towards fast targets than towards slow ones (Bairstow, 1987; van Donkelaar & Lee 1994; Li 1996; Savelsbergh et al. 1992). In addition, Brenner and Smeets (1996) showed that the greater the speed of objects the shorter the movement time. Moreover, Mason and Carhan (1999) have also pointed out that the faster speeds were associated with shorter viewing time (VT, the time that is visible prior to the interception). More obvious advantage of making a faster, briefer movement in an interceptive task is that the briefer the movement, the more time you have to view the target (Breen 1967; Hay 1985). For instance, a longer VT will likely lead to improved perceptual estimates of quantities required for accurate control—the time remaining before the target reaches the person (its time-to-contact, TTC). Certainly, viewing a moving target for a longer period can improve interceptive performance (Elliot et al. 1994; Sharp and Whiting 1974, 1975).

In addition to the temporal accuracy, no previous experiments have evaluated the specific effects of target's height (spatial accuracy) on the performance of interceptive tasks. Tresilian et al. (2004) reported that participants were constrained to move along a horizontal linear track to strike the target with different speed (140 cm/s and 220 cm/s) and different target heights (3 cm, 6 cm, and 12 cm) did not constrain the performance. In addition, movement time was unaffected by target heights but was systematically affected by lengths (4.1 cm, 9.1 cm, and 14.1 cm) (briefer movements to smaller length) and speed (briefer movements to faster targets). Moreover, participants were asked to move in a vertical plane normal to the target's direction of motion. In this task, target height constrains the spatial accuracy required to contact the target. Three groups of eight participants struck targets of different height but of constant length and speed, hence constant temporal accuracy demand (different for each group, one group struck stationary targets - no temporal accuracy demand). On average, participants showed little or no systematic response to changes in spatial accuracy demand on any dependent measure (MT, Vmax, spatial variable error). Brouwer et al. (2005) reported different results using an interceptive task in which no additional constraints were imposed on how participants could move. It was found that when the target moved relatively slow, MTs were greater when the target was smaller; when it moved faster, there was no detectable effect of size on MT. Thus, in some conditions, it appears that requirements for greater spatial accuracy in interceptive tasks can lead to longer MT's.

The interception of target can be completed in many different ways, such as grasping or hitting the object with hand or with implement. With a particular interception of a trajectory, the spatiotemporal accuracy and precision that is needed can still vary considerably. For instance, when the foot lands on the moving objects from kicking, a relatively high degree of temporal precision is required for the interception to take place. But if the moving object is coming toward the kicker less temporal precision may be needed: the kicking foot may not contact the moving object in an optimal timing but the kicking foot and the moving object will collide in their paths. Therefore the spatiotemporal constraint does not only depend on the speed of object and the chosen mode of interception such as kicking, but also on how the person moves and how they are positioned relative to the target paths of motion. It seems reasonable to say that when a person tries to execute a task in such a way to maximize the chances of success, they may try to adopt a strategy, which can lower the requirement of accuracy and precision (Brouwer et al., 2002; Tresilian & Longergan, 2002).

In Taekwondo, back kick consists of four phases, such as the rotation phase, contact phase, kick phase, and restoration phase and back kick plays a very important role in offensive and defensive technique. In addition, the speed and accuracy are two important components of the back kick performance. Based on the previous literature, the speed of object was used to guide the hand to intercept moving target. Thus, the faster the moving object the quicker the hand will react. Nevertheless, there is no study that illustrates whether the lower limb task will follow the same phenomenon. Therefore we need to look at how the lower limb kick of Taekwondo can be guided by the moving target to aid participants to move faster with their feet to the moving target Brouwer, (2002) investigated the two different information needed for subject to hit the moving target, whether only the visual information was used or did it also include the information of the speed. He concluded that participants would only respond to the changes in the target position. However the object speed will influence the direction in which the hand moves indirectly. In a study conducted by Tresilian (2002) where he manipulated the target size and speed of the moving object, it was concluded that the target speed and target size had independent effects on the performance. . In this study we hope to find if the target speed is used in guiding the Taekwondo back kick..

CHAPTER III METHOD

Participant

Ten healthy elite Taekwondo male athletes were recruited from National Taiwan Normal University (age 20 ± 2 years; height 177.9±9 cm; weight 68.9±12.4 kg). All athletes had competition experience of more than 5 years and had trained at least 10 hours a week. They read and sign the informed consent before the experiment.

Apparatus

The Experimenter used a measuring tape (Stanley) to measure the distance between participant's front foot to the sand bag and the leg length from the hip to the heel. Two high-speed cameras (Casio, 300 fps) were placed in a fixed position to record the experiment. Camera 1 was placed 3.5m away from the line of the action in a sagittal view to record the movement time and the moment the participant kicks the sand bag. Camera 2 was placed 2.5m behind the participant to record the contact place of the foot on the sand bag. (See Figure. 2).

Taekwondo Sand Bag (28kg, Kwon) was used as the object for the participants to kick. It was hanged 67 cm away from the ceiling and 70 cm above the ground. A bull's-eye target was attached to the center of the sand bag and the height of the target was adjusted to the height of the participant's abdomen (See Figure 3). Two pieces of 1m x 2.5m cloths were hung from above the sand bag to cover the viewing of the sand bag when the sand bag was pulled backward into three different release angles (30°, 45° and 60°).

A white tape was strapped across the inner and outer arch of the foot for identifying the points scored when kicking the object target. A PC computer was used to run Kinovea video player software to register the temporal information of the kicking tasks

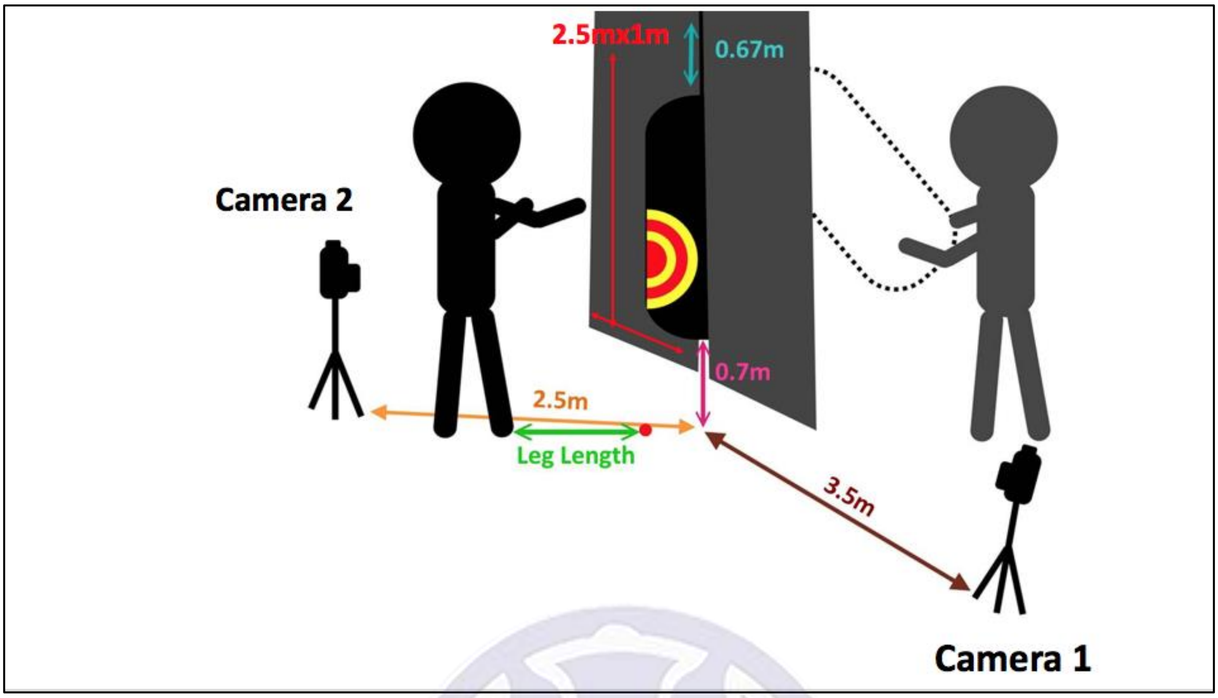

Figure 2. Schematics of the experimental setup.

Figure 3. Target area on the sand bag

Task

The experimental tasks were Taekwondo back kicks toward a stationary or a moving sand bag. There were 10 trials for the stationary sand bag condition (SP1) and 10 trials for each of the 3 moving speeds of the moving sandbag conditions. The speed of the moving sand bag was determined by dropping the sand bag from a release angle of 30°, 45°, and 60° corresponding to 13.95 m/s (SP2), 27.9m/s (SP3), and 41.84 m/s (SP4), respectively, at the instance where the sand bag was passing through the 0° position (perpendicular to the floor).

Procedure

All the participants were informed of the general experimental procedures before they signed the consent form. The participants wore shorts and were bare feet in the experiment. After the experimenter measured the height of the abdomen and the leg length for the participant, the inner and outer arch of the kicking foot of the participant was strapped with a piece of white tape.

Each participant stood in front of the sandbag/cloth screen in a kicking position, facing toward the direction of the kicking target with the pivot foot in front. The distance between the tip of the pivot foot and the projecting point to the floor from the bull's eye of the stationary sandbag was measured to the leg length of the participant. After a 10-minute warm-up (jogging, stretching, and kicking drills, to avoid injury), the participant practiced 3 trials of the kicking tasks for each speed condition. After practice, participant began the back kick experiment and was instructed to kick as fast and as accurately as possible with the sand bag at the perpendicular position to the ground. The experiment included 40 trials of back kick tasks that were randomized from 10 trials by 4 speed-conditions (See figure 4).

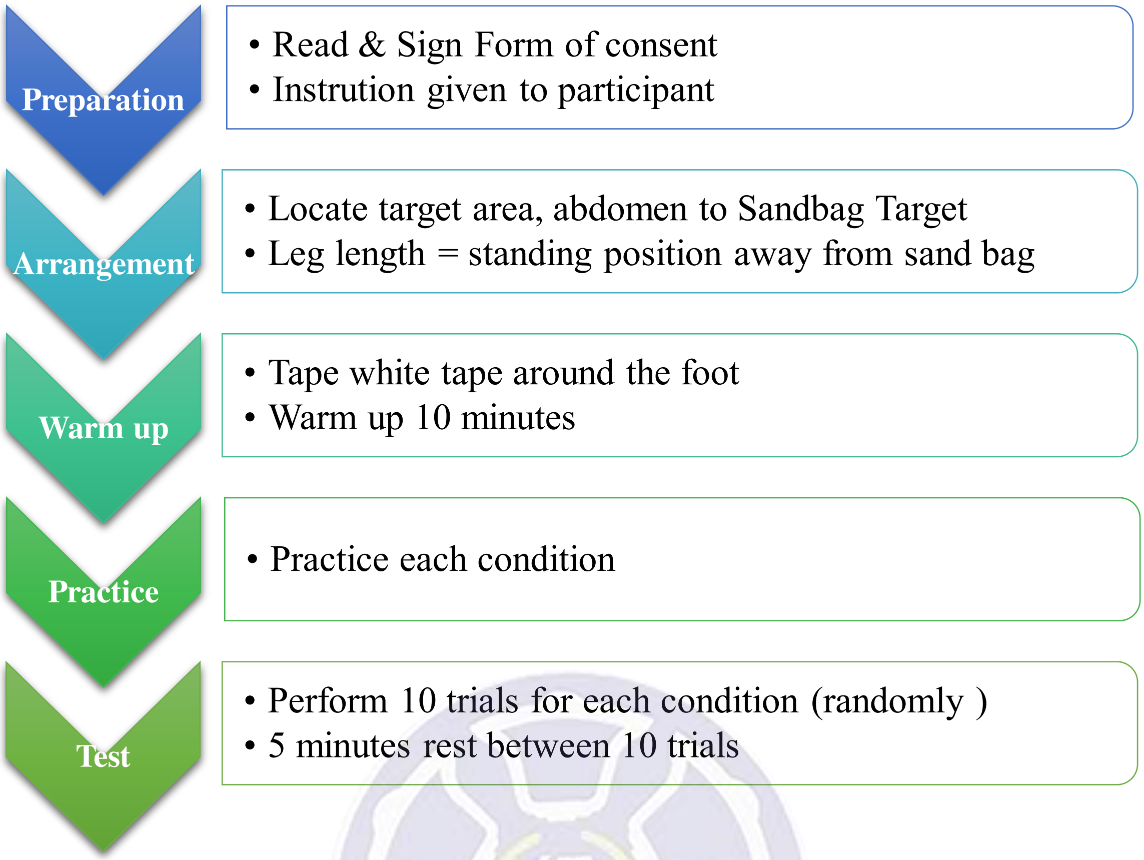

Figure 4. Diagram showing the procedure

Data Analysis

MT was measured as the time between the rise of heel and the foot contact to the sand bag.. TE was measured using the time between the movement initiation of the participant and the moment where the target is perpendicular to the ground. Negative TE indicates the foot-sand bag contact moment was before the sand bag reached the 0° position.(See Figure 5.). MT and TE were examined using the one-way repeated-measures ANOVA for 4 speed conditions. The Greenhouse-Geisser method would be used for the adjustment of the degrees of freedom if the test of sphericity was not satisfied. The η_p^2 effect size was reported according to Cohen (1988) standard.

TSA was recorded based on the contact position of the foot on the location of the target from the video replay of each trial. ASA was registered based on the angle of the sand bag when the foot contact to the sand bag was made. Two black belt Taekwondo international referees ranked the ASA from the perpendicular position (4) to the farthest away from the perpendicular position but closest to the participant (1) (See figure 5). The kappa values were used to examine the intra and inter rater reliability. All the kappa values were higher than 0.8 (Table 1).

The TSA and ASA were examined using Pearson Chi square test of independence for the 4 speed conditions. SPSS 23.0 was used for all statistical analyses where the α level of significance was set at .05.

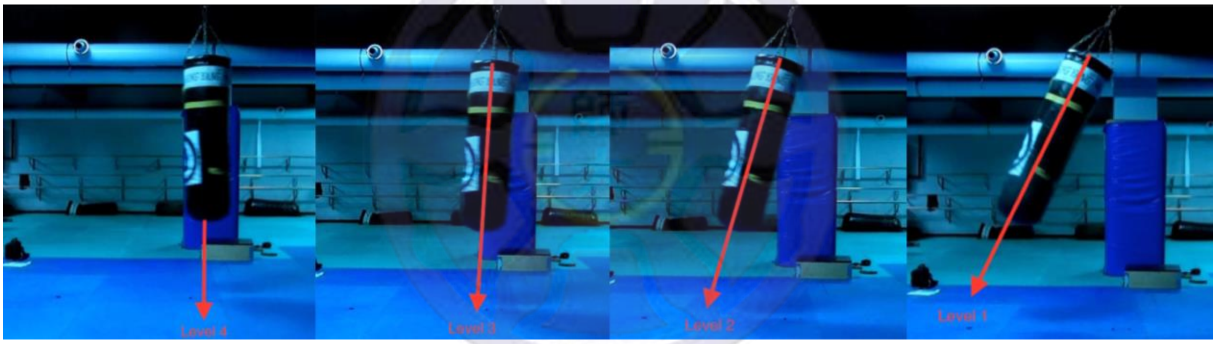

Figure 5. Four spatial accuracy levels of angular position at foot-target contact

Table 1 Kappa values of reliability for the 2 ASA raters

Rater	T	G
T	.887*	.840*
G	-	.954*

Chapter IV Results

Movement time

The average movement time for each participant in four different speed condition were as follows: 0.038±0.017 seconds in SP1, 0.032±0.009 seconds in SP2, 0.035±0.018 seconds in SP3 and 0.027±0.007 seconds in SP4. One way repeated measure ANOVA showed no significant main effect of the 4-speed condition to the movement time of the participant, $F(1.98, 17.78) = 1.865$, $p = .184$ with small effect size $\eta_p^2 = .174$ (Figure 6).

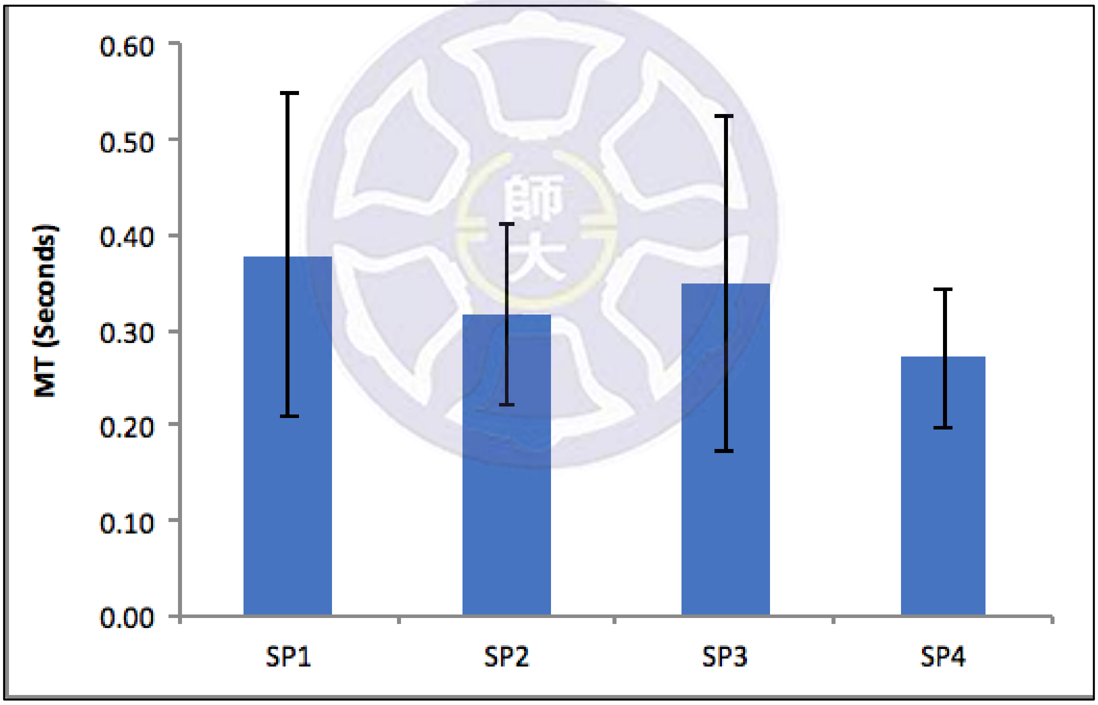

Figure 6. Average movement time in four conditions

Temporal error

The average temporal error for each participant in three different speed condition were as follows: 0.003±0.010 seconds in SP2, -0.001±0.011 seconds in SP3 and -0.003±0.007 seconds in SP4. One way repeated measure ANOVA showed no significant effect of the speed condition to the temporal error, F (1.82, 16.38) = 5.138, p = .21. with small effect size η_p^2 =.363 (Figure 6).

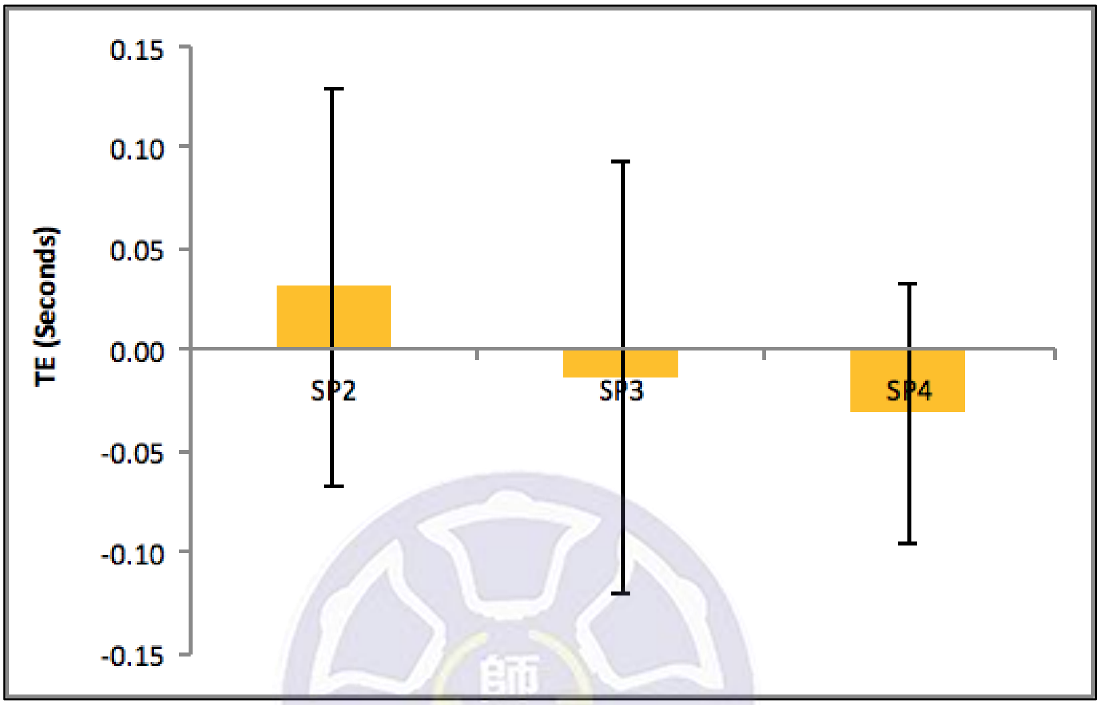

Figure 7. The average temporal error in 3 moving speed conditions

Spatial accuracy on target

The result of the Pearson Chi square test of independence showed that there were significant associations between the target speed and target accuracy, $\chi^2(12)$ =139.60, $p < .05$, *Cramer's V=.341* Examining the adjusted standardized residuals of each of the cells in the cross-tabulation (Table 2), high positive values form an implicit diagonal trend line from the top right to the bottom left (highlighted area in Table 2), indicating a strong association of high target accuracy for the stationary target, medium target accuracy for the medium speed condition, and poor target accuracy for the fast speed condition.

Table 2. Cross-tabulation of frequencies of TSA in 4 speed conditions

	TSA Points					Total
	0	1	2	3	4	
SP1	2	1	23	38	36	100
	(0.5%)	(0.25%)	(5.75%)	(9.5%)	(9%)	(25%)
Residual	-2.6	-5.7	-1.2	3.3*	5.6*	
SP2	1	26	42	19	9	100
	(0.25%)	(6.5%)	(10.5%)	(4.65%)	(4.75%)	(25%)
Residual	-3.0	1.4	-1.5	1.7	.5	
SP3	3	27	42	19	9	100
	(0.75%)	(6.75%)	(10.5%)	(4.65%)	(4.75%)	(25%)
Residual	-2.2	1.7	3.7*	-1.7	-2.6	
SP4	27	30	24	13	6	100
	(6.75%)	(7.5%)	(6%)	(3.35%)	(1.5%)	(25%)
Residual	7.9*	2.6*	-1.0	-3.3	-3.5	
Total Count	33	84	111	102	70	400
	(8.25%)	(21%)	(27.75%)	(25.5%)	(17.5%)	(100%)
Pearson Chi Square			Asymptotic Significance (2-sided)			.00**

*p < .05; **p < .01*

Spatial accuracy of the sand bag angle

The result of the Pearson Chi square test of independence showed that there were significant associations between the speed and the spatial accuracy of the angular position of the sand bag, $\chi^2(6) = 150.58$, $p < .05$, *Cramer's* $V = .501$. Examining the adjusted standardized residuals of each of the cells in the cross-tabulation (Table 3), high positive values were found on level 3 of the angular position associated with the slow speed, medium speed conditions, level 2 of the angular position associated with the medium speed, fast speed conditions, and level 1 of the angular position associated with the fast speed condition.

Table 3. Cross-tabulation of frequencies of ASA in 3 speed conditions

		Angular position of sand bag				Total
		1	2	3	4	
Speed	SP2	0 (0%)	9(3%)	90(22.5%)	1(.33%)	100(33.3%)
	Residual	-4.7	-7.9	10.8*	.5	
	SP3	6(2%)	61(20.3)	32(10.6%)	1(.33%)	100(33.3%)
	Residual	-2.5	5.1*	3.4*	.5	
	SP4	32(10.6%)	52(17.3%)	16(5.3%)	0(0)	100(33.3%)
	Residual	7.1*	2.8*	-7.4	-1.0	
Total Count		38(12.6%)	122(40.6%)	138(46%)	2(.66%)	300(100%)
Pearson Chi Square			Asymptotic significance (2-sided)			.00**

*$p < .05$; **$p < .01$

Chapter V Discussion

Movement time

The first question of the study was to examine if the movement time will decrease when the speed of target increases? The result showed that when the speed of object increased, movement time did not change significantly. This result does not support previous studies of interceptive tasks that showed a tendency to move more quickly towards fast targets (which was moving away from the moving hand that was used to intercept the target) than towards slow ones (Bairstow, 1987). In addition, Brenner and Smeets (1996) showed that the greater the speed of objects the shorter the movement time. In the experiment conducted by Brouwer Brenner and Smeets (2002) suggested that, the movement time would be shorter when the speed of object increased. However, this did not show in the current study and this could be due to the difference in the nature of the tasks.

In Brouwer Brenner and Smeets (2002) the participant intercepted the target that moved at different constant speeds, which would disappear in sight. The disappearance of the target was carried out in a varying amount of time. In this way, it prevented the participant from updating the information during the time that the object disappeared. The target moved on the screen and the screen was right in front of the participant, and the participant had to strike the target with a 22cm Perspex rod. In the current study the speed of object also moved at different speed, however, the disappearance time were not used intentionally to manipulate the viewing time of the object. The target object was moving toward the participant but not away from the participant. Since the object was moving toward the participant the movement time might be limited because the incoming target may limit the distance for the participant to have the ability to move faster as the object speed increases and closing the spatial distance between the object and the participant.

The time the object became visible for the participant was at the perpendicular level to the ground. All participants have limited time to react with the back kick, thus the capability of the participant for a back kick may be limited by the duration of time and the perceived object at the perpendicular level. In Taekwondo competition athletes can move back and forth for an offensive or defensive action; however, during the back kick experiment the participant were required to stay at the place (position) in a distance of their leg length to the target. Furthermore, they were asked not to move from their positions and attack the incoming object until they see it, they were unable to change their distance according to their own preference. This could influence the participant to improve their movement time.

Temporal error

In this study, the participants were instructed to kick as quickly and as accurately as possible once they see the object in the 3 speed conditions. For the current study, the temporal error is defined differently from those found in previous studies In a study conducted by Tresillian (2002), the participants were asked to intercept a moving target with a bat that moved along a straight path and it was constrained by a linear slide. The movement time used to intercept object decreases as the speed of object increases. The speed and object size was manipulated but it gave the same effect on required temporal precision, however the responses to these changes vary, because the target speed brings out larger changes in response speed. The temporal error in the current study is similar to a reaction time but it was a measure between the movement initiation and the moment when the sand bag arrived at the perpendicular level. Because participants produced similar movement times at different target speed conditions, when the target moved in a faster speed, it was difficult for the participants to initiate the movement only after the target became visible at perpendicular. We could not tell if there was any anticipation in the participant because there was no significant effect of speed in TE. . There might be a possibility where the participant had a strategic plan in order to have a head start before seeing the target. For example, the participants might have noticed a bulge at the top of the cloth when the target is near perpendicular.

The no-difference result of the ANOVA may be because of the speeds of the objects were too fast for participants to kick giving them all similar approach to the incoming object. When combining the movement time result it could be seen that participants were not able to increase the kicking speed under the faster target speed conditions. Without appropriate starting signal to initiate the kicking movement, the initiations of the kicking movement were not systematically tied to the speeds of the target.

To sum up, we could not justify that a complete back kick should have the participant intercept the incoming object at the right time and place because the participant will be in contact with the sandbag even if they did not move. In previous study of Tresilian (2002), the participants intercepted a moving object requiring that the interceptive effector (hand or bat) get to the right place at the right time. In addition, in Tresilians (2002), the moving object was moving across the participant, where in this study the object was moving toward the participant, which resulted in a different task. Generally speaking Taekwondo athletes need to have the right TE for the best timing to contact the opponent before the opponent reaches you, and this may vary between people because there are many aspect we need to take into account. The height, movement speed, and reaction time, etc.. The result of this study showed no significant speed effect because the experimental manipulation did not reflect the real life competition.

Target Spatial Accuracy

In this study, the participants were asked to kick as accurately as possible for the incoming object and instructed that the points scored on the target from the bullseye outward were 4, 3, 2, and 1 and 0 points for the kicks missed on the target. The effect of target speed on spatial accuracy was investigated where the SP1 is at stationary. The target spatial accuracy of SP1 was the greatest compared to those of the other speed conditions because the target in SP1 was stationary and visible the entire time to the participant. The distribution of the points scored were significantly associated to the 4 speed conditions, which showed similarity to Brouwer (2002) as the target speed increases it is more difficult to hit the target. The accuracy rate was (73%) for the fastest target and the slow target was (81%). However the target was moving away and not moving toward the participant. Whereas in the current study the participant tried to execute the back kick task where the target was moving toward the participant and the participant were moving directly to the target (Brouwer, Brenner,& Smeets, 2002).

The results of spatial accuracy from the current study did not show similarity to the speed-and-accuracy trade-off phenomenon reported in the literatures (e.g., Woodworth, 1899; Fitts, 1954; Fitts & Perterson, 1964). Although there are similarities in this study that gives the speed and accuracy trade-off, but the given tasks were completely different. In the present study, target moves toward the participant, at the same time the participant moves to the target whereas in studies that followed Fitts' paradigm, the target remained stationary and the distances were manipulated. However, when the participants were instructed to move as quickly and as accurately to the target as possible, they were unable to increase their speed as the target speed increased. Since the MT remained the same and the distance did not change or shortened therefore it did not show the same effect as the speed and accuracy trade-off.

Spatial accuracy of angular position at foot-target contact

There was a significant association between the target speed and the level of angular position at foot-target contact. However, we did not see if the participant adopted an anticipation strategy because there was no significant speed effect in the TE from the movement initiation, we could not say that the participant moved ahead of the sand bag before reaching perpendicular. The result of ASA level showed that the target speed was fast in SP3 and SP4 for them to strike the target at the perpendicular position, thus as the speed of target increased it was more difficult for participants to hit the target near 0° perpendicular to the ground. Since there was also no significant speed effect in movement time, the participant was limited to perform a better ASA.

When the moving target was coming toward the participant at SP3 and SP4, the target speed increased yet the movement time did not decrease which made the position of the target at the foot-target contact further away from the perpendicular. The kicking foot could not contact the moving target in an optimal timing but the kicking foot and the moving target would just collide in their paths. Therefore the spatiotemporal constraint does not only depend on the speed of the target and the chosen mode of interception such as kicking, but also on how the person moves and how they are positioned relative to the target paths of motion.

Conclusions

In this study we found out that elite Taekwondo athletes movement time and the temporal error were not influenced by the speed of the target. Participants have reached the speed limit over the training. It is not likely that they can shorten the movement time any further, therefore it is very difficult for one to suddenly increase the movement speed when the speed of object increases. As the speed of object increased the spatial accuracy, both on target and at the foot-target contact position (ASA), decreased.

For future study, we could manipulate both the target size and speed such as in Tresillian (2002), to see if the manipulations can influence the movement time of the participant. Moreover, we can include different technique such as pushing kick in the experiment and manipulate the different visibility of the object to see if we have the same effect as Brouwer, Brenner and Smeets (2002). We may also manipulate different viewing time of the moving object the for participants (Brouwer, Brenner & Smeets, 2002; Tresilian, 2002) to examine if MT will decrease as the target speed increases at the longer viewing time.

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